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Influence of stand type and stand age on soil carbon storage in China's arid and semi-arid regions

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ABSTRACT

Afforestation implemented on available lands that have a poor fertility with a low primary productivity is considered to be a significant land use change issue globally, especially in the current phase of increasing atmospheric CO_2 concentrations. However, different stand types and stand ages, where afforestation is initiated, may have a different effect on soil carbon storage. Two stand types, including the apricot and poplar stand, both with 40 years, and two stand ages, including the apricot stand with 40 years and apricot stand with 16 years were sampled on the Loess Plateau, to explore the differences in soil carbon storage between both of them, respectively. The results showed that the total soil carbon storage up to the 1.0 m soil depth for the poplar stand was 79.07 Mg ha^{-1}, and for the apricot stand with 40 years was 88.36 Mg ha^{-1}, while for the apricot stand with 16 years, it was 56.16 Mg ha^{-1}. About 50% the soil carbon was stored in the 0-0.4 m soil layer for all these forested lands. This ascertains that the soil carbon was very sensitive to climate change and anthropogenic disturbances. Based on these results, if we are interested in combating global warming issue, the apricot trees can be a preferred option for future plantations. However, these plants are likely to consume more water than any other vegetation types. Since water is a limited resource both in arid and semi-arid regions, a tradeoff between soil carbon and soil water should also be considered in future afforestation policy options.

1. Introduction

Estimatedly, about two-thirds of the terrestrial ecosystems' organic carbon is nominally fixed by forests, and thus, forests are seen to play an important role in the climate system and the global carbon cycle (Fan et al., 2007; Zhong et al., 2017; Tei and Sugimoto, 2018). With global warming as a major environmental challenge (Korkanç, 2014), forest plantation has been considered widely as a strategic way to absorb the CO_2 from the terrestrial atmosphere (Chen et al., 2007; Zhou et al., 2009; Haghdoost et al., 2012; Krause et al., 2018). In China and also in many other nations, the implementation of afforestation is considered to be a strategic policy decision taken for former agricultural lands, marginal croplands, wasteland and deserts, particularly for those that have a poor soil fertility and productivity, to prevent soil degradation and restore the degraded landscapes that were severely affected by soil erosion processes (Cao and Wang, 2010; Zeng et al., 2014; Nunez-Mir et al., 2015; Han et al., 2017). The global total forest area has expanded by approximately 5×10^6 ha y^{-1} over the period 2005 to 2010 (Du et al., 2015), and that forest plantations in China now cover about 6.9×10^7 ha, accounting for one third of the world's total forest plantation areas (Chen et al., 2016). With the inevitable changes in land use, the lands' former short production cycles are extending to a much longer cycle on the forested landscapes (Cao and Wang, 2010; Ren et al., 2016). Although it has been widely reported that afforestation is expected to improve the carbon sequestration (Humpenöder et al., 2014; Han et al., 2017; Lu et al., 2018), there is some evidence that soil carbon sequestration generally varies among the different tree species and age of the plantations (Zeng et al., 2014), because a community of plants is seen to play a dominant role in the soil's carbon accumulation process (Wu et al., 2017).

The Loess Plateau of Northern China is famous for its deep loess and unique landscapes (Liu et al., 2014). However, this Plateau has also become one of the most serious soil erosion regions and the most vulnerable area to the desertification effect, due to long-term,

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unreasonable land use management practices (Fu et al., 2011). To reverse this trend, at least partially, environmental restoration and protection programs have frequently been applied to restrict farming activities and also to increase the vegetative cover on steeper slopes (Liu et al., 2014). For example, in 1978, the Three-North (Northeast, North Central, and Northwest China) Forest Shelterbelt Program, which is the earliest large-scale afforestation program in China (Wang et al., 2011), was implemented. Another such program was also implemented in 1999 known as the "Grain for Green" (Tui Geng Huan Lin) Project. Both programs aimed to return about 32 million ha of cultivated hillside (slope ≥ 25°) lands across China to the forestlands by the year 2010 (Chen et al., 2010).

With the enforcement of these projects into a practical reality to address the landscape degradation and soil fertility issues in non-vegetated lands, different stand types and different stand ages began to co-exist, and their capacities to facilitate the sequestration of carbon were intensively studied (*e.g.* Guo and Gifford, 2002; Chang et al., 2011; Dang et al., 2017). However, due to extensive inconsistency of these results, ground-truth observation data depending on specific locations are still required (Farley et al., 2005; Ilstedt et al., 2007; Jia et al., 2017). This is necessary to better understand the linkage between plantation forestry strategies and the storage of soil carbon (Silva and Dudley, 2009; Dangal et al., 2017), and also to achieve sustainable strategies for land use policy development and implementation of the most appropriate solution (Cao and Wang, 2010; Lu et al., 2016). This can therefore act as an appropriate decision support tool for forest management and culm cutting techniques that are likely to yield optimal benefits from the forest (Dangi et al., 2009).

Huining county, a representative area in the Loess Plateau, has implemented some of these projects. In the 1978 project, both the poplar tree (*Populus tremula* L.) and the apricot tree (*Prunus armeniaca* L.) were planted, while in the 1999 project, only the apricot tree was planted. The poplar stand can be regarded as one form of a pure ecological forest following the belief that the production of poplar could be a potential carbon sink due to the rapid accumulations of above- and below- ground biomass (Zhang et al., 2011). On the other hand, the apricot stand can be regarded as an eco-economic forest, because of its primary goal to reduce soil erosion and also to help farmers to maintain their incomes by sell of the almonds (Cao et al., 2018b). At present, there exist two different stand types (*i.e.*, the 40-year old poplar stand *vs* the 40-year old apricot stand) and two different stand ages (*i.e.*, the 16-year old apricot stand *vs* the 40-year old apricotstand). In a recent study, Cao et al. (2018b) have explored the effects of the stand type and stand age on soil water moisture, but, to date, no report about their influences on soil carbon storage (SC) has been established in any other independent study.

The present paper aims to investigate the influence of the stand type and stand age on SC, to purposely explore the balance between soil carbon and soil moisture based on our previous study (Cao et al., 2018b). In this paper, the hypothesis is that the SC is influenced by either the stand type or the stand age,and that the SC is positively correlated with the stand age. This study synthesizes reliable results to either prove or disprove the proposition, and expects to advance new understanding of SC based on stand type and stand age in China's arid and semi-arid region, that could also have wider implications for other regions where land use and land cover change is being addressed by afforestation options.

2. Materials and methods

2.1. Study area

Huining County (located at 104°29′- 105°31′E, 35°24′- 36°26′N) lies in central Gansu Province at the Northwest Loess Plateau at an average altitude of 2025 m extending over an area of about 6.4×10^5 ha. Annual average temperature in this region ranges from 6 °C to 9 °C with an annual rainfall of 180–450 mm, mainly attributable to a temperate semi-arid climate. The region is characterized by complex tectonic structures, most of which are based on metamorphic rocks and granites.

By the end of 2015, the county's total afforested areas had reached to about 7.1×10^4 ha, representing a forest coverage rate of approximately 12.47% (Cao et al., 2018b). In the county's northern and central regions, although the trees planted in 1978 were deforested for wood, some forests have been protected integrally up till now. Together with the trees planted in 1999, this provides a good opportunity for researchers, such as the one pursued in this paper, and also for land use policy-makers to explore the effects of the stand type and stand age on SC.

2.2. Experimental design

During the period July to September 2017, four sites were selected as the sampling area, the greater details of which are available in an earlier study of Cao et al. (2018b). In each forested site, nine plots were arranged both in an up-down fashion and on the contour at a 10 m spacing. In all these sites, 81 plots were investigated, and each forested land type had a total of 27 plots. In each plot, a set of three 1 m × 1 m quadrats, spaced along the diagonal (*i.e.*, at both ends and a midpoint), had their soil profile excavated to a depth of 1.0 m. Soil samples were taken for a profile depth range of 0-0.1 m, 0.1–0.2 m, 0.2–0.4 m, 0.4–0.6 m, 0.6–0.8 m and 0.8–1.0 m, using a cutting ring whose volume was equivalent to 1×10^{-4} m^3 (Wu et al., 2016). A soil depth of 1.0 m is likely to reflect the main root distribution of the forest (Han et al., 2017). In each quadrat of the apricot stand, above-ground biomass (AGB) was collected. While in the poplar stands, vegetative cover and plant diversity were very low due to the physical barrier of litter (Fig. 1C) to germination (Chen et al., 2015), so AGB was not collected.

2.3. Soil and biomass analysis

Soil bulk density (SBD g cm^{-3}) was determined from the undisturbed core segments as the dry soil mass per unit volume, while the soil organic carbon (SOC g kg^{-1}) was determined with wet dichromate oxidation using an air-dried homogenized subsample of 0.2 g soil and titration with $FeSO_4$ (Qin et al., 2016). Fresh biomass was oven dried at 80 °C to a constant weight (over a 24 h period) and was then expressed by the dry weight (g) (Cao et al., 2013). The SC in each soil layer was calculated following existing methods (Shang et al., 2014):

$$SC_i\,(t\ ha^{-1}) = C_i \times SBD_i \times T_i \tag{1}$$

In Eq. (1), C_i is the concentration (%) of SOC in the i^{th} soil layer, and T_i is the thickness of the soil layer.

The total of soil carbon storage (TSC) in 1.0 m soil depth can be stated as follows:

$$TSC = \sum_{i=1}^{i=6} SC_i = \sum_{i=1}^{i=6} C_i \times SBD_i \times T_i \tag{2}$$

2.4. Data analysis

Data were analyzed using SPSS 22.0 statistical software (SPSS Inc. Chicago, USA), and expressed as the mean ± standard deviation. One-way analysis of variance was applied to determine the statistically significant differences in the soil pH, SBD and SOC between the different stand types and stand ages at equivalent to a significance level stipulated by a value of $p \le 0.05$. The Pearson's Product Moment Correlation (r) was used to identify the statistically significant relationships between the measured variables. The Origin Pro 9.0 software was then adopted to visualize for the data through appropriate visual and statistical diagnostic plots.

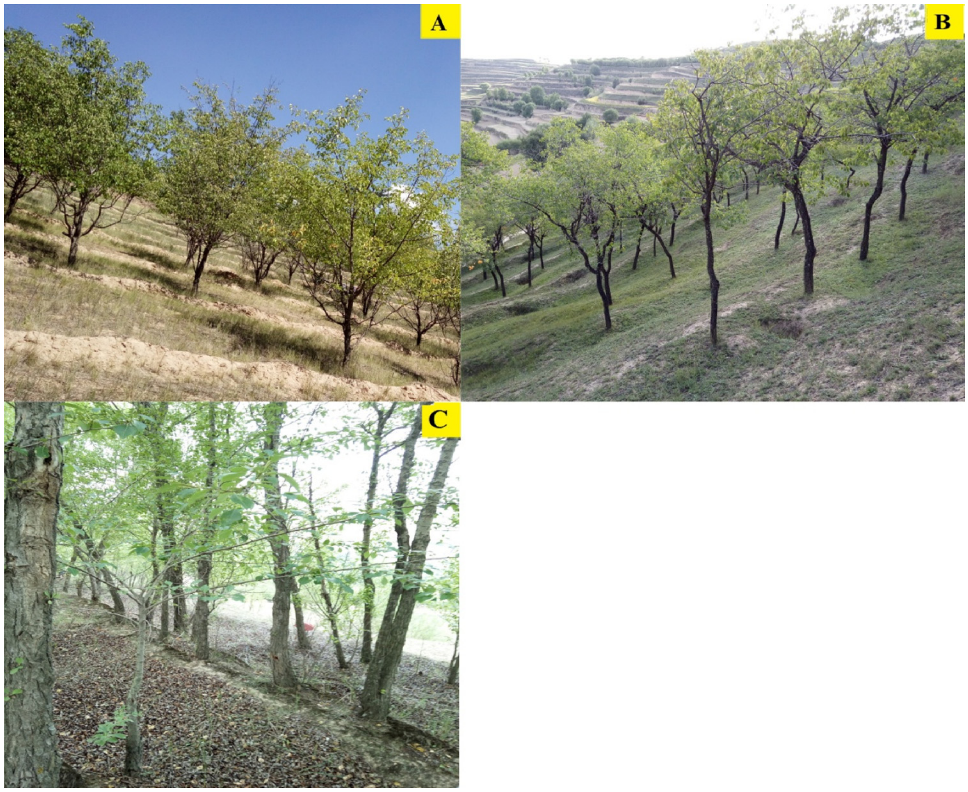

Fig. 1. Pictorial representations of the sampled lands in the present study. A: 16-year-old *Prunus armeniaca* L.; B: 40-year-old *Prunus armeniaca* L.; C: 40-year-old *Populus tremula* L..

3. Results

3.1. Soil properties and vegetation in different stand types and stand ages

The average SBD, SOC, and TSC up to a 1.0 m soil depth in the apricot stand with 40 years were all significantly higher than that in the poplar stand and apricot stand with 16 years (Table 1). From the 16-year-old to 40-year-old apricot stand, the SBD, SOC and TSC appeared to have been increased to about 0.05 g cm^{-3}, 2.84 g kg^{-1} and 31.20 t ha^{-1}, respectively, while AGB had decreased to about 17.38 (g m^{-2}).

3.2. Vertical distribution of SBD, SOC, and SC in different forested lands

In the poplar stand, although the SBD in the 0.1–0.2 m soil layer (1.18 g cm^{-3}) was significantly different from that in the 0.8–1.0 m soil layer (1.13 g cm^{-3}), it was similar among the other soil layers; in the apricot stand with 16 years, the SBD in the 0–0.4 m soil depth was relatively larger, and no differences were found among the 0–0.1 m (1.21 g cm^{-3}), 0.1–0.2 m (1.19 g cm^{-3}), and 0.2–0.4 m (1.20 g cm^{-3}) soil layers, but below the 0.4 m, it decreased dramatically; in the apricot stand with 40 years, significant differences in SBD were found among the 0.4–0.6 m (1.17 g cm^{-3}), 0.6–0.8 m (1.12 g cm^{-3}) and 0.8–1.0 m (1.09 g cm^{-3}) soil layers, and their values fluctuated as the soil depth was increased. From the 0–0.1 m (1.21 g cm^{-3}) to the 0.1–0.2 m (1.20 g cm^{-3}) and 0.2–0.4 m (1.18 g cm^{-3}) soil depths, the SBD exhibited a slight decrease, but no differences were found among these three soil layers. From the 0.4 m to the 0.8 m soil depth, the SBD increased, and then decreased in the 0.8–1.0 m soil layer. The highest SBD was found in the 0.6-0.8 m soil layer (1.23 g cm^{-3}), but it was only significantly different to that in the 0.2–0.4 m soil layer (1.18 g cm^{-3}) (Fig. 2A).

Table 1
Soil properties and the above-ground biomass in the poplar stand and apricot stand (including the 40years and 16 years), respectively.

Variables	Poplar stand	Apricot stand (40 years)	Apricot stand (16 years)
SBD (g cm^{-3})	1.16 (± 0.11)[a]	1.21 (± 0.08)[b]	1.16 (± 0.08)[a]
SOC (g kg^{-1})	7.31 (± 3.41)[a]	8.06 (± 4.14)[b]	5.22 (± 2.53)[a]
TSC (Mg ha^{-1})	79.07 (± 26.21)[a]	88.36 (± 27.95)[b]	57.16 (± 17.20)[a]
AGB (g m^{-2})	–	18.38 (± 7.88)[b]	35.76 (± 25.42)[a]

Note: SBD = soil bulk density, SOC = soil organic carbon, TSC = total soil carbon storage, AGB = above-ground biomass, '-' = no measured data. Letters: differences between the poplar stand and apricot stand with 40 years, and between the apricot stand with 40 years and with 16 years.

In any of the forested lands, the SOC appeared to exhibit a notable decrease as the soil depth was increased, and it was mainly distributed in the 0-0.4 m soil depth. The SOC in the 0-0.4 m soil depth in the apricot stand with 40 years was relatively higher than that in the poplar stand. From the 0.4 m to 1.0 m soil depth, the SOC in the apricot stand with 40 years decreased significantly in a relatively faster manner compared to that in the poplar stand, being from 6.25 g kg^{-1} to 5.19 g kg^{-1} for the former, and from 6.18 g kg^{-1} to 5.63 g kg^{-1} for the latter, respectively. Compared to the apricot stand with 40 years and poplar stand, from the 0.4 m to the 1.0 m soil depth, the results showed the SOC values for the apricot stand with 16 years were relatively stable (Fig. 2B).

A variation in SC with an increase in soil depth and its distribution in the soil layers are presented in Figs. 3 A and Fig. 3B, respectively. The SC in the top 0.4 m soil depth was about 50% of the total in the 1.0 m soil depth for both the poplar stand and apricot stand with 16 years, and 55% for the apricot stand with 40 years (Fig. 3B).

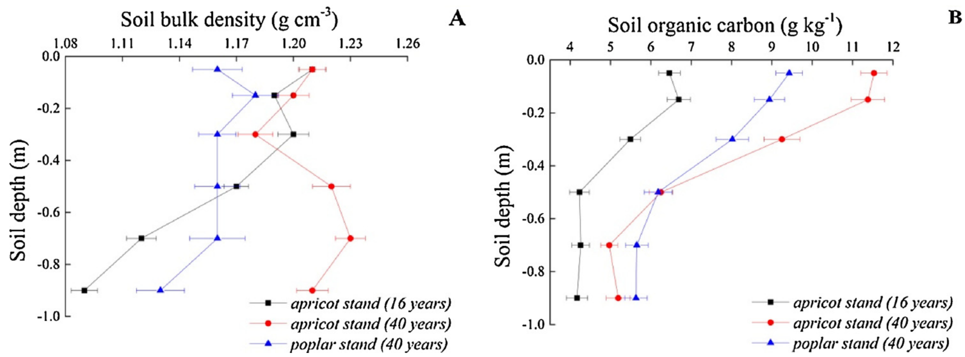

Fig. 2. Vertical distribution of the soil bulk density and soil organic carbon in the poplar stand and apricot stand (including the 40 years and 16 years), respectively.

4. Discussion

4.1. The reasons for vertical distribution of SC in forested lands

Differences in the rooting depth patterns among the tree species can affect the vertical placement of SC within the soil profile (Laganière et al., 2017). In this study, we found that the SC exhibited a decrease as the soil depth was increased from the 0 m to the 0.4 m, and then, its variation was negligible in the deeper soil layers in all forested lands. This, however, was mainly concentrated in the top 0.4 m soil layer (Figs. Fig. 22B and 3), and was in agreement with the earlier study of Jin et al. (2014) and Charro et al. (2017). It estimated evident from earlier studies that the average SC after the afforestation of former arable land was likely to be about 1.1 Mg C ha^{-1} yr^{-1} to a soil depth of the 0.4 m in China (Shi and Cui, 2010). In this study, if we consider that the amount of SC in these forested lands was equal in each year, then the annual rate of soil carbon sequestration at this regional level is likely to be similar to that at the national level. This equates to anominal value of 1.2 Mg C ha^{-1} yr^{-1} for the poplar stand, 1.0 Mg C ha^{-1} yr^{-1} for the apricot stand with 40 years, and 1.2 Mg C ha^{-1} yr^{-1} for the apricot stand with 16 years (Fig. 3A).

Although the aboveground biomass in the apricot stand with 16 years was significantly greater than that in both the poplar stand and the apricot stand with 40 years, the SC of it was the lowest (Table 1). This suggests that the stored carbon in the top soil layer was not determined primarily by the above-ground litter as it happened in the other case study (Laganière et al., 2017), but rather by the plants roots and their exudates (Zhao et al., 2015; Wu et al., 2017). The vertical distribution of the SBD may also be considered to be a factor that influences SC distributions, because the low SBD often has a better soil structural stability (Han et al., 2017), which is attributable to a higher content of the organic matter (Chen et al., 2015). In the present study, we also found that the SBD was significantly related to SC (r = -0.15, $p <$ 0.01).

To further explain this phenomenon, we now compare Fig. 2A with Fig. 3A, that shows the inverse variation trend between SBD and SC. Evidently, this shows that the trend was more conspicuous under the 0.3 m soil depth in the apricot stand with 40 years. However, the SC in the apricot stand with 16 years was seen to vary to much lesser extent but SBD was seen to change dramatically. From the 0 m to the 1.0 m soil depth, the SBD in the poplar stand appeared to vary slightly less, but the SC appeared to change a relatively extent. This suggests that the relationship between the SBD and SC can be mainly be determined by the apricot stand with 40 years, and in other two stand types, they were not correlated when the data from the apricot stand with 40 years were excluded from the analysis and interpretation. Therefore, the relationship between vertical distribution of the SBD and SC requires a further independent study.

The highest SBD under the 0.3 m soil depth in the apricot stand with 40 years (Fig. 2 A) may be related to the issue of compaction (Rytter, 2016), which is similar to the tramping issue in grasslands (Cao et al., 2018a, c). As described above, the apricot trees in the present study were planted not only for reducing the soil erosion but also for maintaining the incomes of the locals. Comparison with the apricot stand with 16 years, the compaction rate was higher in the apricot stand with 40 years, owing to the long-term disturbance (*e.g.*, almonds collections) by the locals and grazing influence by the livestock. Generally, if there is an overburden pressure on the upper soil layer, a larger value of SBD is likely to appear at lower layers of the soil profile (Ghuman and Sur, 2001; Bronick and Lal, 2005).

4.2. Influence of the stand type on SC

The influence of tree species by their different biological processes on the chemical properties of the soil is a critical question asked by many practitioners in soil science and biogeochemistry (Menyailo et al., 2002; Zeng et al., 2014). Considering this notion, the understanding of the species induced the SC patterns can provide us crucial insights into the potential impacts of a shift in the stand type on SOC sequestration and the continental carbon balance (Laganière et al., 2017).

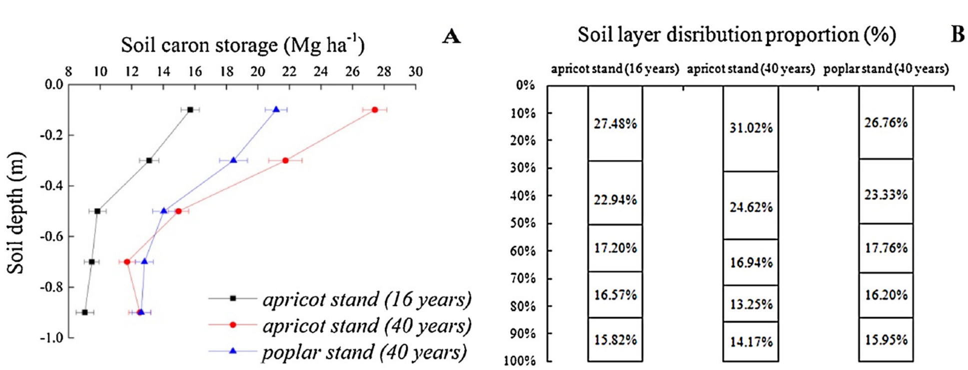

Fig. 3. Soil carbon storage and soil layer distribution proportions in the poplar stand and apricot stand (including the 40 years and 16 years), respectively.

In this study, the TSC in both the poplar stand (80 Mg ha^{-1}) and apricot stand (88 Mg ha^{-1}) (Table 1) were far lower than the average SC in the forested soils across China (194 Mg ha^{-1}) (Zhou et al., 2000). However, these were equal to the average SC in Medicago sativa soils in this region (84 Mg ha^{-1}) (Liu et al., 2017). It is therefore averred that these two stands have a limited role in governing the net carbon pool of a forest-carbon system. It is interesting to note that the TSC in the poplar stand was lower than that in the apricot stand with 40 years, and this deduction accorded to Shen et al. (2014). In terms of a physical interpretation, we can state that not only afforestation policies with the different vegetation coverage are likely to affect the SC, but also the land use type even with the same vegetation coverage, such as grassland managed by multi-households and grassland managed by single-household, can have some effects on SC and the resilience of grassland ecosystem (Cao et al., 2017, 2018a, c)

In spite of a lack of vegetation under the poplar stand, litterfall under this scenario (*e.g.*, Fig. 1C) was much higher than the apricot stand with 40 years (Fig. 1B). Generally, litterfall is likely to contribute to a greater amount of carbon into the underlying soil. For example, the annual litterfall contribution to the aspen stand inthe soils in Canada was found to be about 1.2 Mg C ha^{-1} (Laganière et al., 2013), but in the present study, it seemed that the quantity of litterfall had a little effect on the SC, as also confirmed by Lajtha et al. (2014). Importantly, this suggests that the litter quality can be a relatively stronger driver compared to the litter amounts, a finding that accedes those of previous studies (*e.g.*, Laganière et al., 2017).

Previous studies have also shown that the leaf litter of poplar trees are likely to exhibit a greater decomposition rate due to a high concentration of soluble carbohydrates and low concentration of lignin (Hobbie et al., 2000; Cao et al., 2014). Moreover, the poplar fine roots may have relatively short-lived lifespan (Finér et al., 1997) and thus represent a faster decomposition rate than the apricot fine root (Block et al., 2006). As the present study area constitutes a semi-arid continental climate, the accumulated litterfall at the soil surface could be easily decomposed with minimal leaching of nutrients (Zeng et al., 2014). In addition, as described in terms of the above mechanism, while the aboveground vegetation may have no effect on vertical distribution of SC, it may also influence the TSC by increasing the additional litterfall into the soil in apricot stand with 40 years (Boča and Miegroet, 2017). All of these effects are likely to result in a greater amount of SC in the 0-0.4 m soil depth in the apricot stand with 40 years compared to the poplar stand. However,under the 0.6 m soil depth, the SOC in the poplar stand was larger than that in the apricot stand with 40 years (Figs. 2B, 3A). This finding may be attributed to a deeper rooting system of poplar (compared to the root system of apricot), which could lead to more root-derived carbon inputs into the deep soil (Tong et al., 2016).

4.3. Influence of the stand age on SC

With the expansion of afforested areas and increasing stand age, it is critical that wetake into account the assessment of soil carbon budget with plantation time (Zhang et al., 2011; Zeng et al., 2014; Dang et al., 2017). Previous studies (*e.g.*, Dangal et al., 2017) have found that the SC is likely to decrease with the increase in the stand age, due to an increase in the rate of organic matter decomposition and variation in the soil's hydrothermal regime for maintaining tree survival. However, in this study, we found that the TSC in the apricot stand with 40 years was significantly higher than that in the apricot stand with 16 years (Table 1), suggesting that apricot at old-growth stage could still maintain productivity as the other tree species (Kashian et al., 2013; Tong et al., 2016; Selecky et al., 2017). A primary cause of this is that the litterfall often increases with the size of the trunk (*i.e.*, the average diameter at a breast height for the apricot trees with 40 years being 138 mm, and for the apricot trees with 16 years being 102 mm in study area (Cao et al., 2018a)). The litterfall is not only likely to contribute to fresh organic matter, but it may also provide a protection that could act to improve the humification process within the underlying soils (Han et al., 2017). In addition, the respiration of roots depending on carbon allocation below-ground and accounting for half of the soil CO_2 effluxes, is likely to decline with an increasing stand age, and thus a gradual accumulation of the soil carbon is likely to occur (Zeng et al., 2014). However, as the canopy density increases with the stand age, the understory vegetation development may be limited (Zeng et al., 2014) as found in this study: the AGB in the apricot stand with 40 years was only one half of that in the apricot stand with 16 years (Table 1). Besides this, the water consumption may also increase as the age of the apricot stand increases (Cao et al., 2018b), leading to less soil water availability for the understory vegetation, mainly because the apricot trees with 40 years have a better access to deep water sources (Nosetto et al., 2005; Cao and Wang, 2010; Cao et al., 2016).

One plausible reason for less SC in the apricot stand with 16 years is that apricot trees may still be in the initial developmental phase. As the tree continues to grow, it must maintain a higher carbon turnover rates and greater metabolic activities within the roots that are responsible for the uptake of nutrients (Zhang et al., 2011), and thus depletes the soil carbon to establish the root system during its rapid growth phase (Davidson et al., 2002). This could also be confirmed by smaller SBD values in the apricot stand with 16 years (Table 1), since the growth of the tree is likely to loosen up the soils to forage for nutrients and water, thus acting to increase the soil porosity and reduce the SBD.

4.4. Tradeoff between soil carbon and soil water in forested lands

In this study, we found that both the stand type and the stand age have a notable effect on SC, and that the SC is positively related to the stand age. This supports our initial proposition (see, the introduction section). In the 1.0 m soil depth, with the same age, TSC in the apricot stand was higher 10% than that in the poplar stand, but soil water moisture in the latter was (10.22%) about 1.7 times than that in the former (5.89%) (Cao et al., 2018b), suggesting that positive impact from the apricot stand to the SC comes at a price in terms of soil water as pointed by Cao et al. (2011) and Cao and Zhang (2015). Based on our calculation (not shown here), we found that the apricot stand with 40 years could consume about 406 m^3 ha^{-1} water more than the poplar stand with the same age. The potential benefits of this amount of water could be expressed in terms of water opportunity costs, because the water lost can no longer be used for other purposes, such as to meet residential, industrial, and agricultural needs (Zhang et al., 2016).

According to the market price of carbon and water in China, the latest price of carbon (26, April 2018) was about 58 RMB Mg^{-1}, and the price of water around the same period was about 3.0 RMB m^{-3}. From this, we can infer that the net loss from apricot is about 679 RMB ha^{-1}. To change our way of thinking, let us consider that about 300 m^3 water has the ability to irrigate 1/15 ha wheat field, which could potentially yield about 0.35 Mg wheat. If the market price of wheat is 1.2 RMB/500 g, then the net loss from apricot is about 598 RMB ha^{-1}. Regardless of the calculation method, the apricot trees with 40 years have less potential economic benefits, including those derived from their almonds (Cao et al., 2018b). We can similarly calculate that the net loss of apricot stand with 16 years as about 1053 RMB ha^{-1} comparison with it with 40 years, because SC in the former was less 30 Mg ha^{-1} than that in the latter, and water in the former (8.44%, Cao et al. (2018b)) was larger 229 m^3 ha^{-1} than that in the latter. It is interesting to note that a decreasing trend of soil water with the increase of stand age or cultivation ages of crops was also found by other researchers (*e.g.*, Kou et al., 2016; Huang et al., 2018) in the Loess Plateau. This was perhaps because the amount of water consumed by trees was over the amount of water replenished from deeper soil (Cao et al., 2018b).

In summary, the economic value (those in terms of carbon and water) of these forest lands can ordered as: poplar stand > apricot stand with 40 years > apricot stand with 16 years. Even these apricot

trees with 16 years are likely to accumulate carbon as they get old, but they can consume more soil water as those with 40 years. Therefore, the present policies of afforestation for this particular case must proceed with caution (Cao et al., 2018b) since in arid and semi-arid regions, soil water is considered as a main resource that can limit amicable future policies on revegetation (Chen et al., 2010; Wu et al., 2016; Cui et al., 2018), and it may also serve as a driver for ecohydrological processes (Liu et al., 2018). It is therefore perceived that forest management may not succeed in their mission unless the ecological, economic, and societal factors are also considered in a synergetic manner in order to derive realistic and strategic policies that are able to consider scientific evidence into future forest management options (Cao, 2011; Cao et al., 2016; Sun et al., 2017).

5. Recommendations for forest management

Based on a set of field experiments and a subsequent synthesis of the results, this study suggests that although the annual soil carbon sequestration rate of the apricot and poplar species at a regional level is similar to the average national soil carbon sequestration rate. However, the total potential carbon sequestration is relatively small, and in fact, it may be less than half of the average carbon sequestration of afforestation across China. This is because semi-arid and arid regions can have an inherently low water use efficiency (Gao et al., 2014). Based on this logic, trees species planted in this study area have a very limited carbon pool function. Furthermore, these trees are difficult to be promoted in terms of their continued growth after a certain age (Zhang et al., 2016) because most of the energy they assimilate in this process is likely to be allocated for their survival and maintenance and there may be no extra feedback to the soil (Seedre et al., 2015). When this becomes a reality, the so-called ‘old-man small-trees’ is likely to be observed in the Loess Plateau (McVicar et al., 2007; Cao et al., 2011; Jia et al., 2017).

Based on acomparison of soil water moisture among the other types of land use including the abandoned lands (9.24%) and arable lands (9.16%), it is ascertained that the poplar stand has the highest soil water moisture (10.22%) in this region (Cao et al., 2018b). Notwithstanding this, the poplar species can also be a preferred artificial forest in this arid and semi-arid region and in practice,we recommend that a larger amount of diverse native species assemblages should be used. These could include the apricot + poplar tree plantations, adopted to attain a balance between the soil carbon and soil water since a monospecific tree plantation may be insufficient to fully restore the soil properties (Santos and Scotti, 2018). This could also have wider implications for other regions where land use and land cover change is being addressed by future afforestation options.

6. Conclusions

In the present study area, the stand type and stand age both have a significant influence on soil carbon storage to the 1.0 m soil depth. The apricot stand with 40 years has the highest soil carbon storage capacity, which in terms of its nominal value, was more than 10% compared to the poplar stand and about 35% compared to the apricot stand with 16 years. However, about 50% of the total carbon to the 1.0 m soil depth was stored in the 0-0.4 m soil layer for these forested lands.

Taken together with our previous study on the stand type and stand age on soil moisture content (Cao et al., 2018b), this study has provided additional scientific evidence that the apricot stand with 40 years has the largest amount of soil carbon storage, while the poplar stand has the lowest amount of water consumption among the main land use types.

Considering these, it is recommend that the poplar species should be a preferable option for tree plantations if we are concerned about limited water resource, but there must also be a tradeoff between soil carbon and soil water, to help policy-makers to focus on land use decisions.

Declarations of interest

None.

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